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DIFFUSION AND PULSATIONS IN SLOWLY ROTATING B STARS

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Abstract. Diffusion in cool B stars of the main sequence has been shown to strongly affect opacities and convection in cool B stars of the main sequence. We show here that diffusion in B stars maintains or enhances the excitation of pulsations in these stars. This result conflicts with observations as cool B stars that show evidence of diffusion, the HgMn stars, are stable to the current detection level. We discuss possible implications of this discrepancy for the models.

1 Diffusion and opacities in cool B stars

Slowly rotating B stars on the main sequence are thought to be extremely stable as there is only limited convection in the outer envelope and none at the surface, mass loss is expected to be small and rotational mixing is also negligible. In such a stable environment, diffusion should proceed with few impediments. Consequently, the large abundance anomalies observed in HgMn stars are understood to be the result of diffusion in the atmosphere of such stars.

That diffusion occurs in the atmosphere suggests that diffusion also occurs in the interior in the absence of mixing processes. Richer, Michaud & Turcotte (2000) and Richard, Michaud & Richer (2002) (see also Richard in these proceedings) have shown that radiative levitation pushes iron-peak elements up in the envelope of hot A and cool B stars. While these elements are radiatively supported throughout the outer envelope of these stars, they tend to accumulate at a temperature of roughly 200 000 K because of a local reduction of the outward flux there. At such a temperature, iron-peak elements are the dominant contributors to the opacity and, naturally, as they accumulate, the opacity also increases locally. Figure 1 shows the abundance profiles of two models, one with significant diffusion and another where the effect of diffusion is only marginal. An overabundance of the order of a factor of ten is achieved in the former.

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With the notable exception of Hydrogen, lighter elements that play an important role in the opacity at lower temperature are generally not supported by radiative pressure and therefore sink out of the superficial regions toward the core. Consequently, their contribution to the opacity diminishes.

The combined effect of the evolution of the chemical composition as a result of diffusion yields a marked increase in the opacity at around 200 000 K and, perhaps somewhat surprisingly, an increase of the opacity at lower temperatures, as shown in Figure 1, due to the combined increase in the opacity due to hydrogen and iron.

Notice that the abundances are homogeneous from the surface to a point deeper than 200 000 K ($\log T = 5.3$). These low temperature regions are artificially homogenized with an ad hoc turbulent mixing coefficient. In one respect this allows us to tweak the level of chemical anomaly in order to investigate the effect of diffusion in the star's interior. Unfortunately, it also means that the structure of the cool regions of the envelope may be significantly inaccurate.

2 Pulsations in cool B stars

The kappa-mechanism due to the opacity of iron-peak elements is responsible for variability on the lower main sequence (Pamyatnykh 1999). The SPB stars (Slowly Pulsating B stars; see Pamyatnykh) are long-period pulsators found in chemically normal young main-sequence stars earlier than B8. The distribution of these stars overlap in the H.-R. diagram those of the chemically peculiar but seemingly stable HgMn stars.

Apart from variability and surface chemical composition these two classes of stars are very similar. Interestingly, SPB stars are found to be mostly slowly rotating stars, as are the HgMn stars, but the lack of rapidly rotating SPB stars may well be only a selection effect. This suggests that there might well be a correlation between the chemical composition and the excitation of the pulsations, as in Am stars where diffusion leads to stability, or that the conditions that allow diffusion are not conducive to pulsations occurring.

The best models currently available (Turcotte & Richard, submitted) do not however support the hypothesis that diffusion can undermine the excitation of pulsations. As the opacity bump due to iron-peak is enhanced as a result of diffusion in those models, they suggest that the excitation of pulsations in HgMn stars should be at least as high than in chemically normal SPB stars. Again in Figure 1, the differential work for a given mode of pulsation is shown in a model with nearly normal composition and one with strongly enhanced iron and opacity in the driving region. The net normalized growth rate, which must be positive for a mode to be unstable and for the star to become variable, for this mode is 0.08 in the “normal” model and 0.22 in the “peculiar” model. The peak in the driving region is higher, but there is also more damping on the hot side of the peak. In this mode the net driving is in fact considerably enhanced, but in many modes, especially in more evolved models, the net excitation (the value of the normalized growth rate) is surprisingly insensitive to the magnitude of the abundance anomalies. Nevertheless, one must conclude that the models are lacking

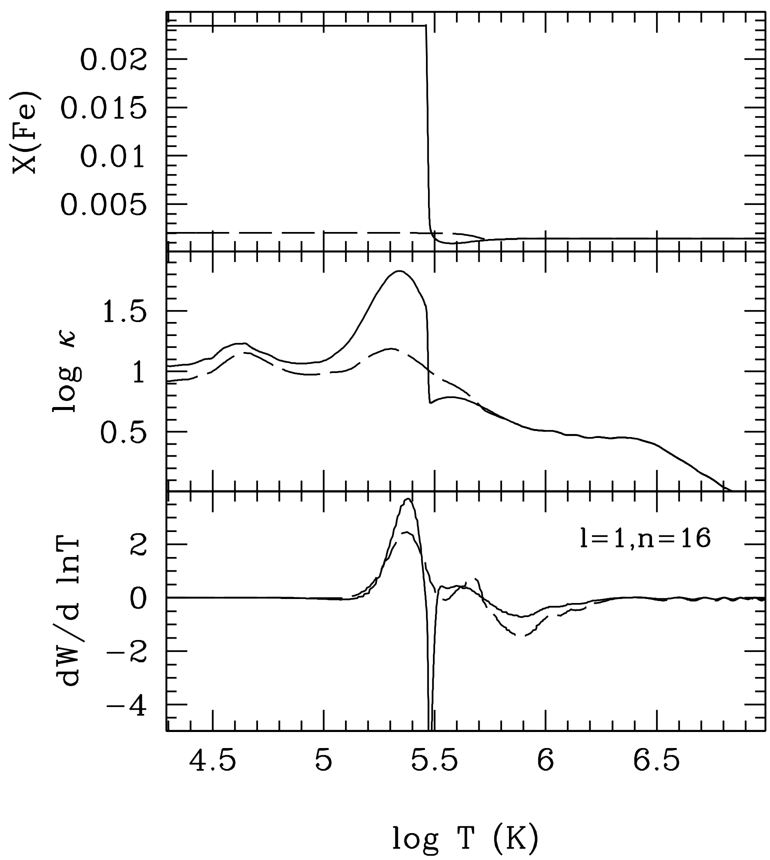

Fig. 1. The figure illustrates the effect of diffusion on the excitation of pulsations in the model of a 10 Myr old 4 $M_\odot$ star. Two models of the same age and mass are compared, one with only marginal change in abundances (dashed line) and one with more efficient diffusion (solid line). The top panel shows the iron abundance profiles; the middle panel the mean Rosseland opacity; and the bottom panel shows the differential work for a $\ell = 1, n = 16$ mode with a period of 1.2 days. A positive work indicates mode excitation while a negative value indicates damping. By integrating the differential work over the whole star we obtain the total work integral which is used to calculate the normalized growth rate (see text).

the necessary ingredient to explain the lack of observed pulsations in HgMn stars.

3 What does this tell us about cool B stars?

We can speculate as to what is the missing ingredient in the models.

We can first argue that adding mixing in the interior of HgMn stars would not resolve the discrepancy as the result of mixing would be to homogenize the composition to its initial, here solar, value. This would still leave too much iron-peak elements in the pulsations' driving region, leading to the expectation of pulsations in HgMn stars as in SPB stars.

A possible solution may be the selective mass loss of certain elements from radiation pressure in the atmosphere but not others (Babel 1995). It is possible that this may lead to the depletion of some elements in the driving region. The detailed process by which this depletion would occur, if indeed it can, has not been worked out yet.

Another possibility is that the issues of mode selection, interference or visibility that often befall the asteroseismology of pulsating stars obscures any direct conclusions we can hope to make on models and stellar physics from the observations.

Finally, our models are lacking in one crucial aspect. Our current models cannot model the region cooler than 200 000 K consistently because of numerical problems. Therefore the structure of the models there may not be appropriate. Though the work integrals seem rather insensitive to those regions, a substantial change in structure there may lead to smaller predicted excitations.

The major stumbling block to improved models is the lack of opacity spectra appropriate to model diffusion consistently at low temperatures (Leblanc, Michaud & Richer 2000). Only when this will be possible will the full picture of mode driving in HgMn stars be achieved. Before then, the models remain informative of the processes that occur in the interior, but speculative as to the net effect of diffusion of mode damping.

Observationally, the advent of space-based experiments dedicated to asteroseismology will eventually resolve the question of whether HgMn stars are really stable or if they undergo undetected low-amplitude variations. Observations are underway to identify faint HgMn stars at the VLT so they can thereafter be observed in the planetary field of CoRot. Whether very-low amplitude modes are detected or not, these observations will pose important new constraints on the models.

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